Climate Model Validation Using Spectrally Resolved Shortwave Radiation Measurements

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*How well* do climate models reproduce observed variability in Earth's climate system and *why*?

SIF 2013 Project Goals

- Why use *direct measurements* of reflectance?

- Why *hyperspectral* sampling?

- Demonstrate using the information in highly accurate, hyperspectral shortwave reflectance measurements for climate model validation

- Does shortwave hyperspectral model validation tell the modelers something new about model performance?

What have we learned from hyperspectral reflectance variability?

- Helped to define CLARREO shortwave imager requirements
  - Variance insensitive over broad range of spectral resolutions
  - Information content enhanced with continuous spectral sampling
  - Nadir-viewing sufficient to capture full variability
- Detection: Identified temporal patterns on several scales (seasonal, annual, and longer periods) - e.g. Arctic sea ice
- Attribution: Linked physical variables to spectral variance drivers (water vapor, vegetation, etc.)
- Comparison: Intersection for spectral, temporal, and spatial quantitative comparison between multivariate data sets
- Model Validation: Comparing variability of spectral observations and model output to evaluate climate models

Roberts et al., 2011*, JGR; *Roberts et al.*, 2013, ACP

Hyperspectral Radiation for Attribution
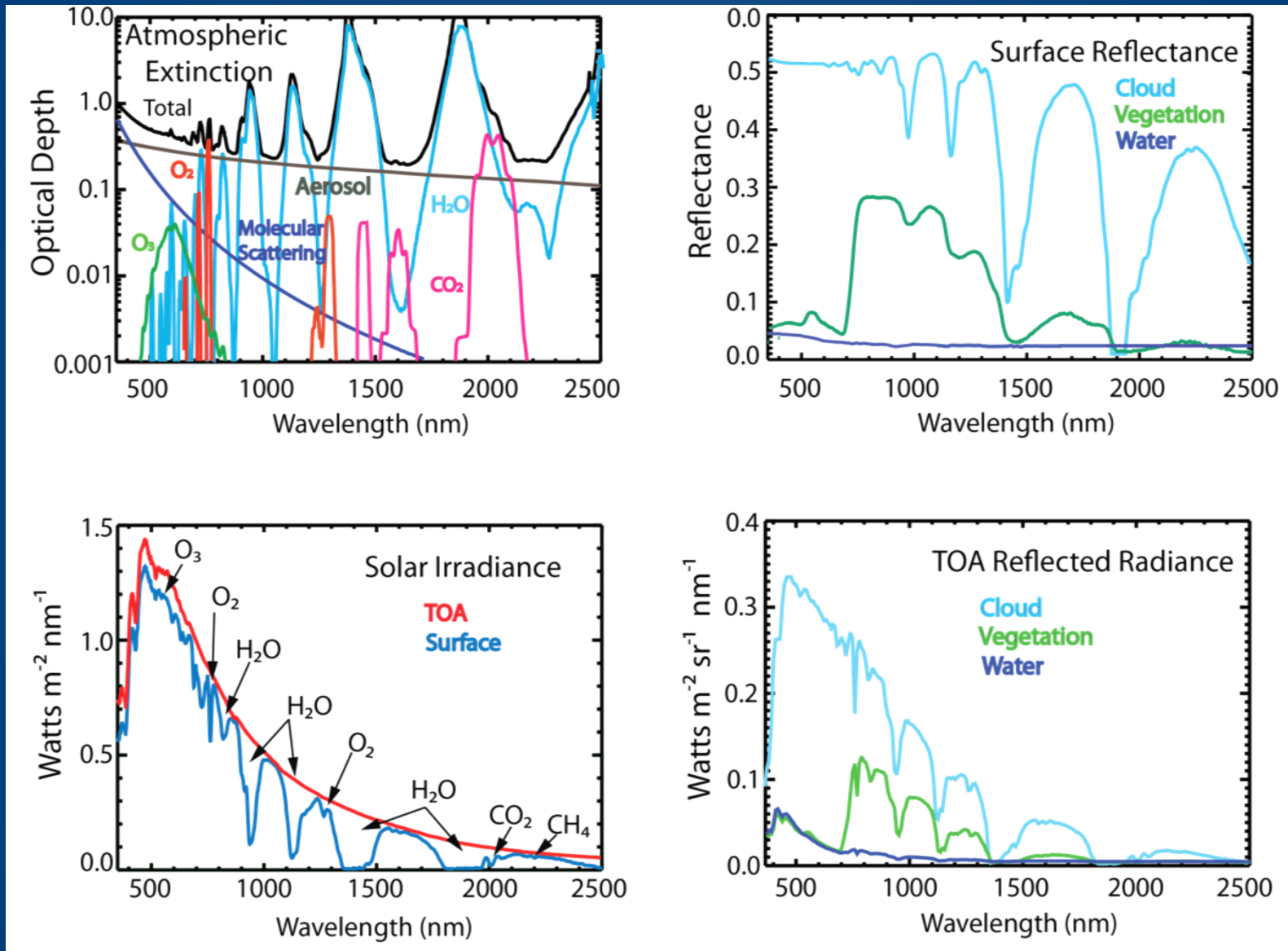
Project Deliverable: SCIAMACHY-based validation product prototype

- SCIAMACHY CLARREO-like validation product
  - Spectral Resolution: 8 nm FWHM
  - Spectral Sampling Resolution: 4 nm
  - Spatial Sampling: 5.625 degrees (T85 * 4)
  - Temporal Sampling: Monthly averages
  - Output Format: netCDF
- MODIS-like and broadband values calculated from same data set
- Variables Included: Clear sky and All Sky reflectance and radiance, IGBP surface IDs, cloud optical properties, etc.

OSSEs - Observing System Simulation Experiments: Simulated CLARREO Radiances

Inputs	IPCC AR4 climate model simulations
Climate Model	CCSM3 simulations 2003-2010
Radiative Transfer Model	MODTRAN v5.3
Scene Type	All Sky and Clear Sky Radiance
Emission Scenario	A2 Emission
ENVISAT-like Orbit	10AM Descending Node

Feldman, D. R., C. A. Algieri, J. R. Ong, and W. D. Collins (2011), CLARREO shortwave observing system simulation experiments of the twenty-first century: Simulator design and implementation, J. Geophys. Res., 116, D10107.
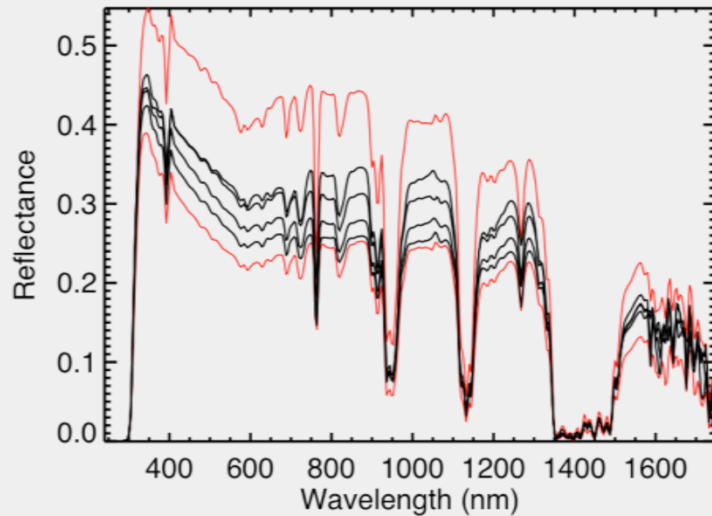
Self Information and Earth Reflectance

**Self-Information:** Information content associated with the outcome of a random variable.

$$I(R_n) = \log_2\left(\frac{1}{P(R_n)}\right)$$

1. How many *hyperspectral* reflectance spectra are within $.55\sigma_\lambda$ of the spectral mean?
2. How many *multispectral* reflectance spectra fall within the same spectral boundaries as in (1.)?
3. How many *broadband* reflectance values fall within the boundaries as in (1.), integrated over the spectral range?
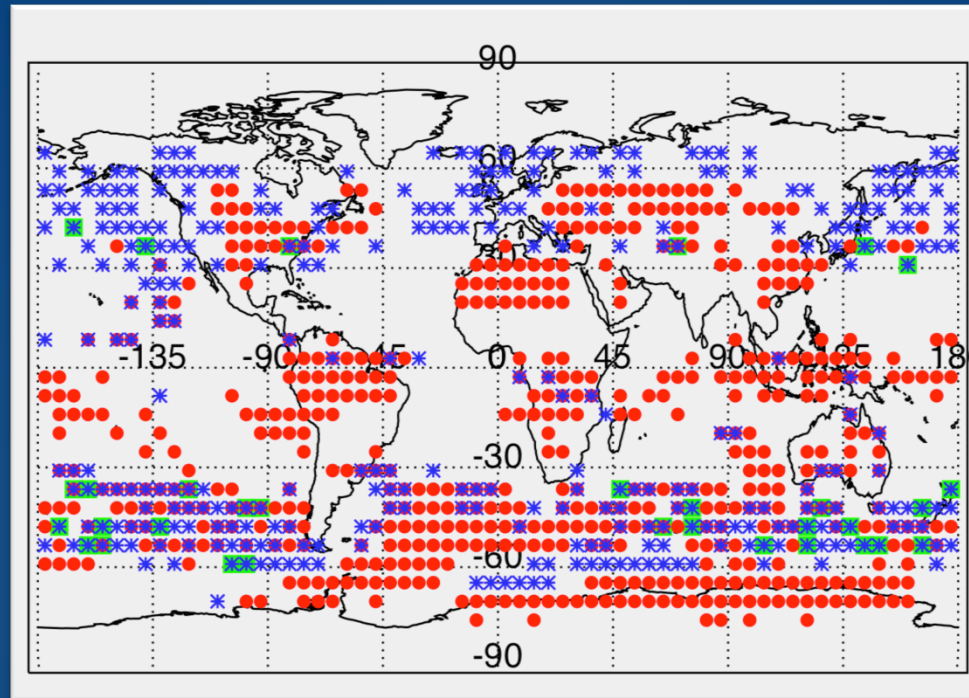
Self Information and Earth Reflectance
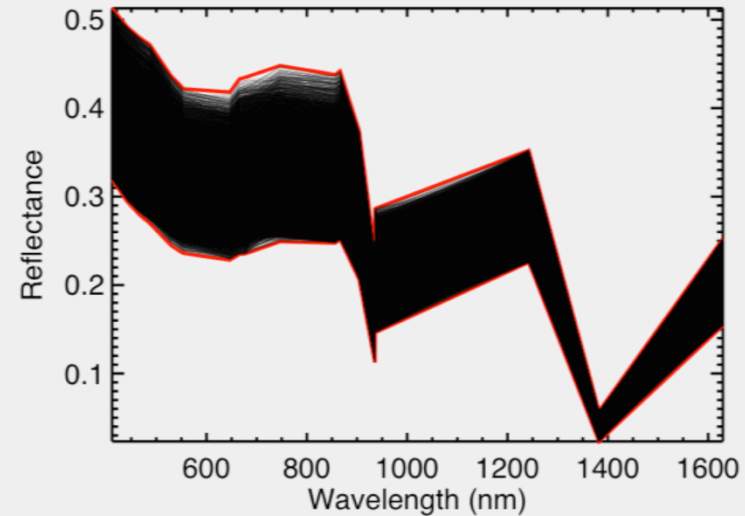
	Data Set	Probability	Self-Information
■	Hyperspectral	2.4×10^{-5}	15.348 Bits
*	Multispectral	0.110	3.179 Bits
	Broadband + 2 Bands	0.205	2.288 Bits
•	Broadband	0.380	1.396 Bits

Self Information and Earth Reflectance

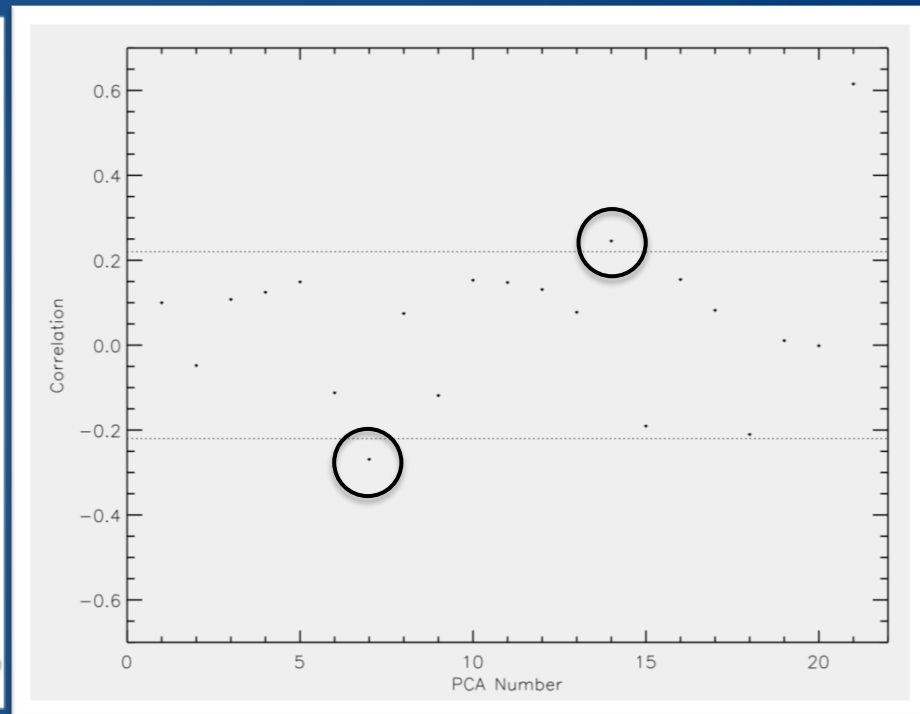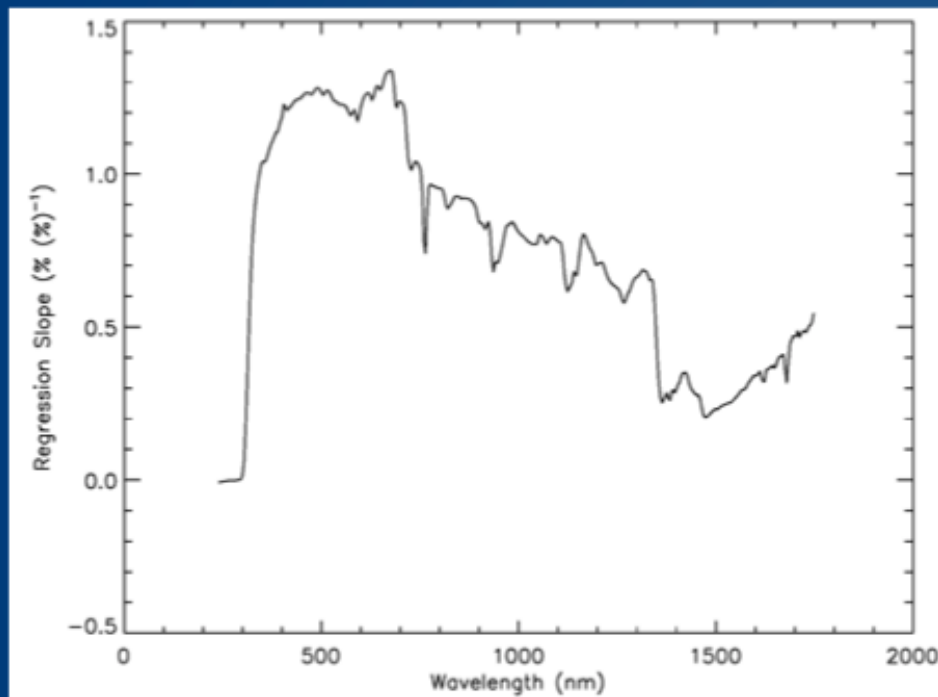|	Data Set	Probability	Self-Information
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Differences in Data Set Information
Regional Domain: Arctic Ocean Poleward of 73°N
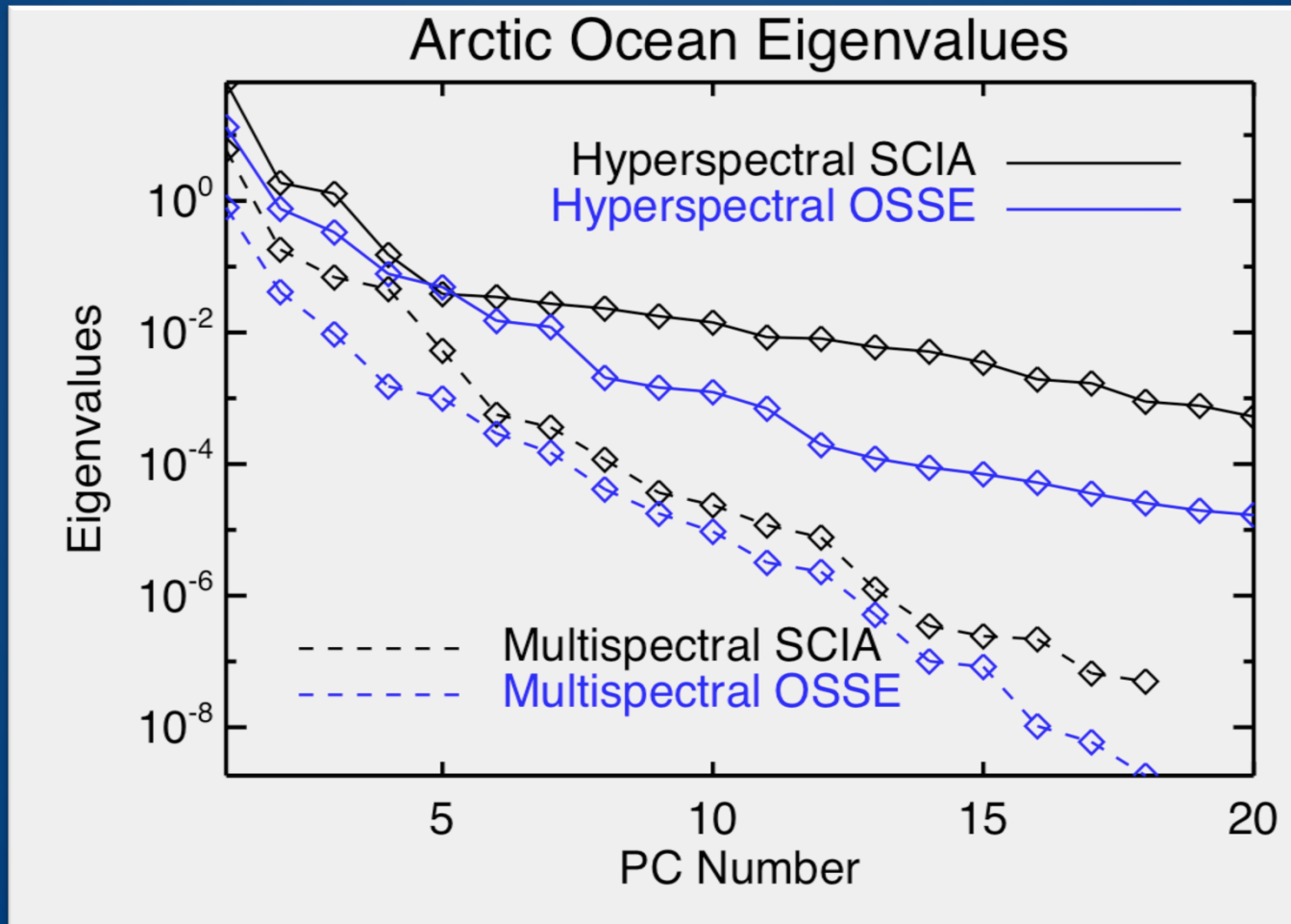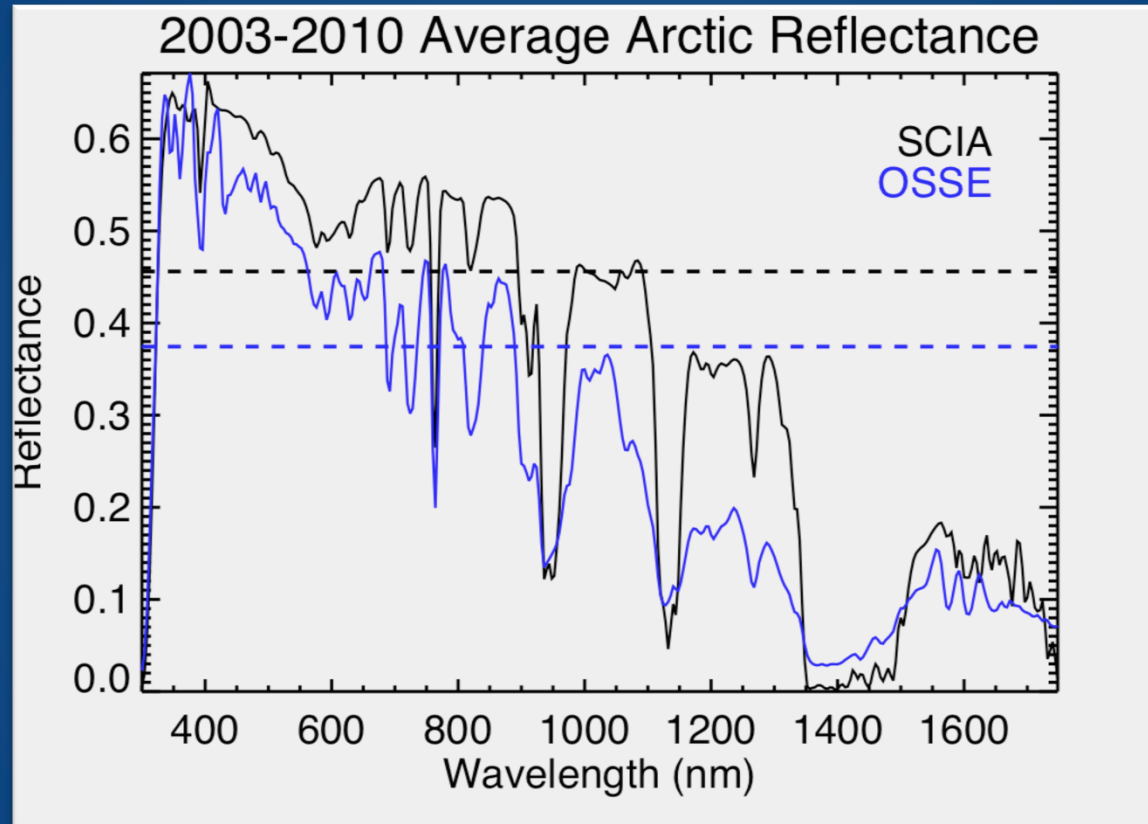
Differences in Data Set Information
Regional Domain: Arctic Ocean Poleward of 73°N

PC1-PC3 are statistically significant. The temporal variability of these dominant spectral modes does not temporally co-vary significantly with the corresponding broadband data set.

Arctic Hyperspectral and Broadband Averages
Regional Domain: Arctic Ocean Poleward of 73°N

2003-2010 Average Arctic Reflectance

The *hyperspectral* comparison and differences contain *more information* about the data set differences than the broadband comparison.
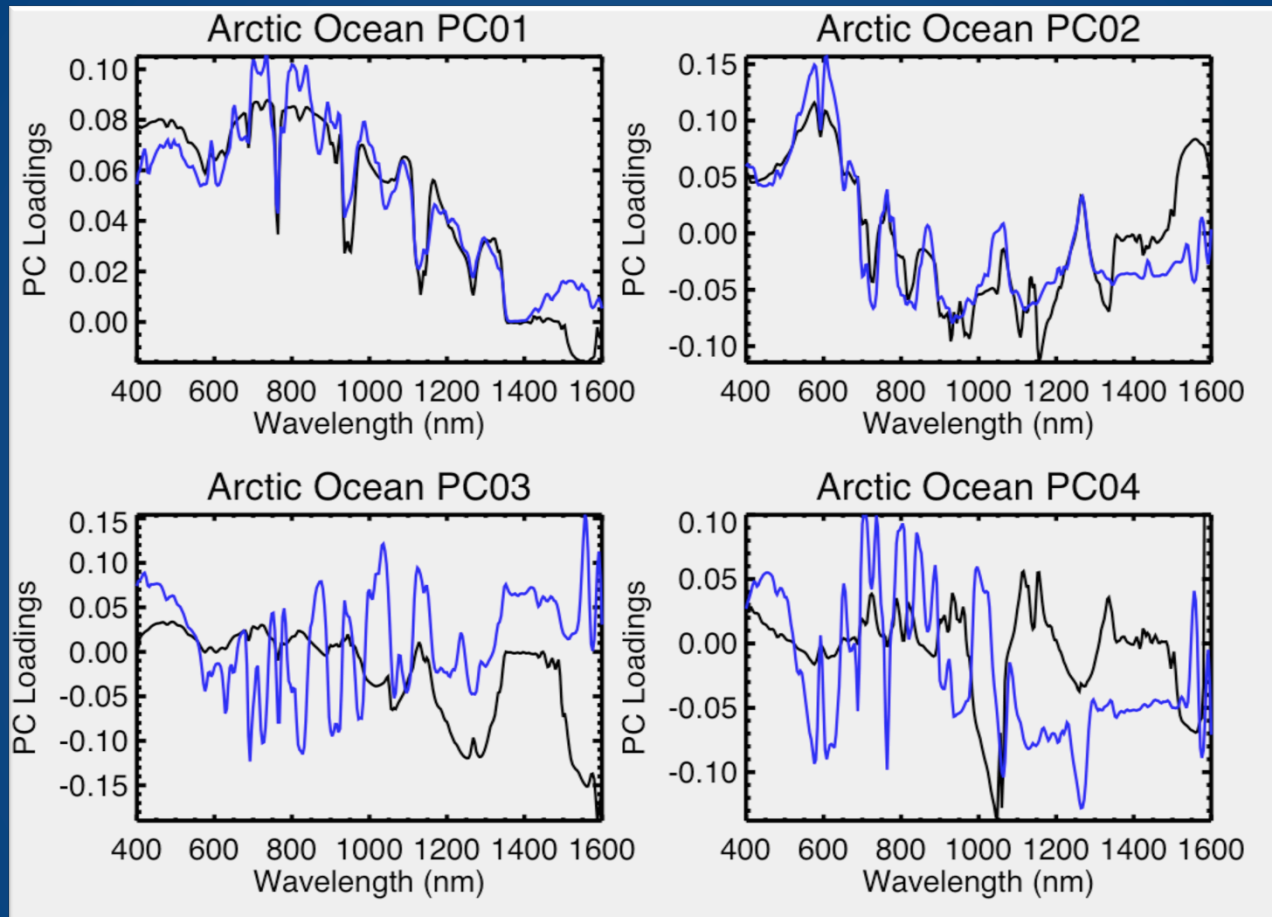
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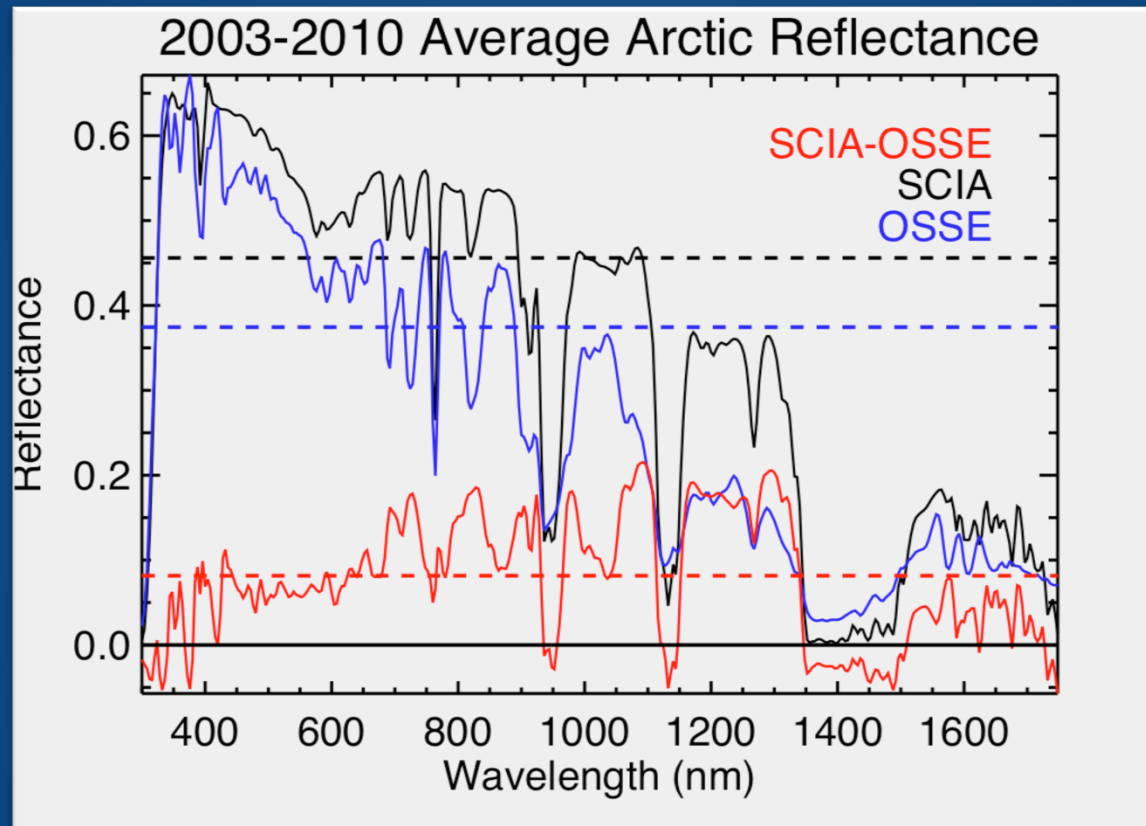
The *hyperspectral* differences show the spectral shape of the differences and reveal that there are both positive and negative differences not captured by the broadband.
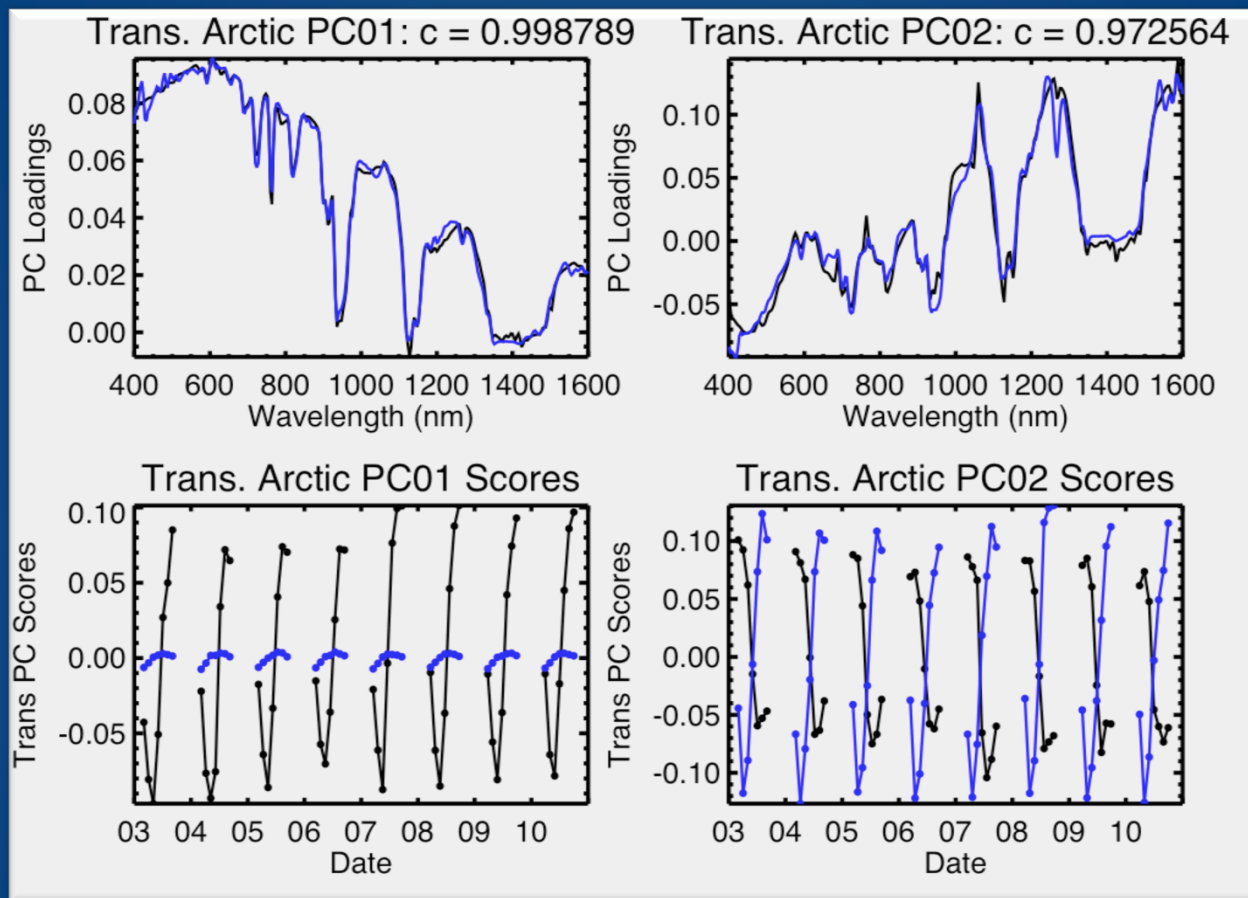
Observed and Modeled Spectral Variability

Arctic spectral variability reveals differences among dominant, independent modes of variability between the observations and model.
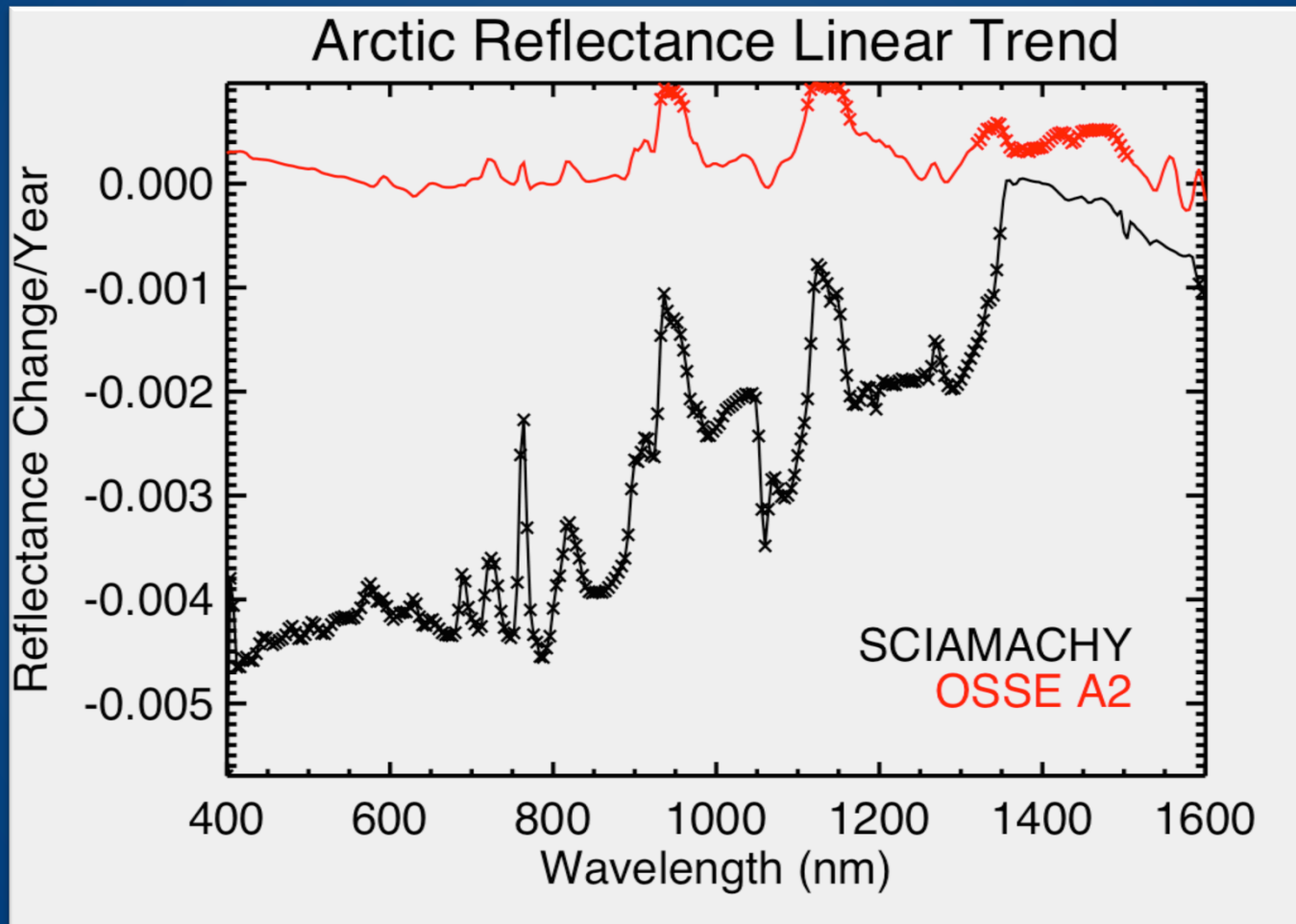
Intersecting Spectral And Temporal Variability

Using the spectral intersection between these two data sets allows for the direct comparison of the temporal variability.

Roberts et al., 2013, ACP; *Roberts et al.,* In preparation

Comparison of linear trends

Arctic Reflectance Linear Trend

SIF Project Summary

- Produced SCIAMACHY-based hyperspectral reflectance validation product prototype
- Simulated SCIAMACHY-like reflectance using OSSE and SCIA sza to emulate ENVISAT orbit (10AM equator crossing time, descending node)
- Direct measurements of hyperspectral reflectance being used to develop methods for climate model validation
- Quantified and demonstrated differences in information among broadband, multispectral, and hyperspectral data sets in general sense
- Using several techniques, compared the variability between modeled and simulated data sets
- Intersecting variables show the spectral nature of the data set overlap and provide direct temporal and spatial comparison between spectral variables
- Future Investigations: Focus on refining comparison techniques, and continuing to develop attribution methods

Future Work

- *Why* are climate models able to or not able to reproduce the variability in the Earth's climate system?

  - Attribution: Continued development of SW hyperspectral attribution techniques will help us to identify physical reasons two data sets have differing and/or similar spectral variability

  - e.g. Shortwave Spectral Fingerprinting, Spectral Matching, RandomForest

- How well do climate models other than CCSM3 reproduce the variability in Earth's climate system?

- Evaluate Self Information over different time/space scales and dependence on measurement accuracy for variety of spectral sampling (e.g. hyperspectral, multispectral, broadband)

- Continue making case for value of hyperspectral measurements for climate model validation: How do broadband and hyperspectral data vary together on decadal time scale?